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CLIMATOLOGY OF NOCTILUCENT CLOUDS ACCORDING TO OBSERVATIONS PERFORMED DURING THE IGY

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CLIMATOLOGY OF NOCTILUCENT CLOUDS ACCORDING TO OBSERVATIONS PERFORMED DURING THE IGY

V. V. Sharonov

ABSTRACT

The paper contains the data of noctilucent clouds distribution with respect to dates, latitudes and longitudes for the IGY period. These data are obtained by a large network of the USSR Hydrometeorological Service stations situated on the territory of the USSR.

As is known, noctilucent clouds were discovered by V. K. Tseraskiy in Moscow, and independently by Hess in Germany in 1885. However, in the last 70 years their appearance has not been regularly recorded, and reports have been published in the literature primarily on observations carried out by individuals. Frequently observations were carried out by chance with other researchers. Due to this fact, data have been compiled slowly and are not systematic. This represents one of the reasons why, up to the present, we have not known with any certainty what produces such aerosol clouds. /143*

When the IGY program was formulated, noctilucent clouds were first proposed for regular observations, and this proposal was adopted in Resolution Number 24 of the II Assembly by the Special Committee on the 1954 IGY, which recommended "visual observations of special pehnomena such as noctilucent clouds".

Noctilucent clouds are studied from a climatological point of view in order to establish the frequency with which these forms of atmospheric aerosol are formed as a function of the geographical position of the observational post, time, different processes in the stratosphere and troposphere, certain cosmic factors, and particularly (with respect to the MGSS problems) as a function of the solar activity phase. The main difficulty encountered here lies in the fact that, in contrast to other geophysical phenomena, noctilucent clouds cannot be seen either in the daytime, or at night. They can be observed optically only at twilight, and then only when there are no clouds in the low atmospheric levels. But even under these conditions, a noctilucent cloud can only be detected at definite points on the earth's surface having the following characteristics (Figure 1).

* Note: Numbers in the margin indicate pagination in the original foreign text.

It can be assumed that the mean altitude of the atmospheric layer in which noctilucent clouds are formed is 82 km. At such an altitude, the dip in the visible horizon is approximately 9°, while the range of the visible horizon - along the great circle arc of the earth's surface from the nadir point of the cloud - is more than 1,000 km. The cloud is thus located above the horizon at a region on the earth's surface which is defined by a circle having a radius of 1,000 km, with the center at the nadir point of the cloud. This determines the conditions for viewing the cloud from the geometric aspect, and leads to the fact that one and the same cloud can frequently be observed from several stations which are not too far removed.

From the astronomical viewpoint, the conditions under which the cloud can be viewed boil down to the fact that it must be illuminated by the sun. As can readily be seen, this is determined by the fact that its projection on the earth's surface (nadir point) must be no more than 1,000 km from the terminator. Finally, from the photometric viewpoint, the conditions under which the cloud can be observed can be reduced to /144 the fact that its brightness must significantly exceed the brightness of the sky background. This is completely impossible during the day, because the brightness of the cloud is approximately 5-10 times less than the brightness of the diurnal sky. But at twilight the conditions are different.

Since the scattering indicatrix for cloud particles is greatly extended ahead - i.e., in the direction of the solar rays - the brightness of the cloud is great enough for stations located primarily in that portion of the geometric visibility region which extends from the cloud nadir in the opposite direction of the terminator. A certain zone on the earth's surface is located at this point, from which the cloud can be actually observed. The dimensions of this zone are determined by the cloud density.

With respect to the investigation conditions, noctilucent clouds have a great deal in common with the aurora polaris from a climatological point of view. The latter are also visible from stations located at a great distance from their nadir; it is difficult to make a quantitative determination of them, and they can be observed only in clear weather and only in a certain portion of the day. But the situation is somewhat simpler for the aurora polaris, because from the illumination standpoint the visibility conditions remain approximately stable throughout the entire night. The time at which noctilucent clouds are visible - the daytime - is characterized by a constant and rapid change in the brightness of the celestial vault. It is for this reason that the number of cases in which they are visible changes greatly with the depth D of the solar depression, rapidly increasing from zero for small D up to a sharp maximum for D = 10°. After this, it rapidly decreases to zero when D = 18°, as is shown in Figure 2.

It follows from the information presented above that only a portion of the actually-existing noctilucent clouds will be recorded no matter

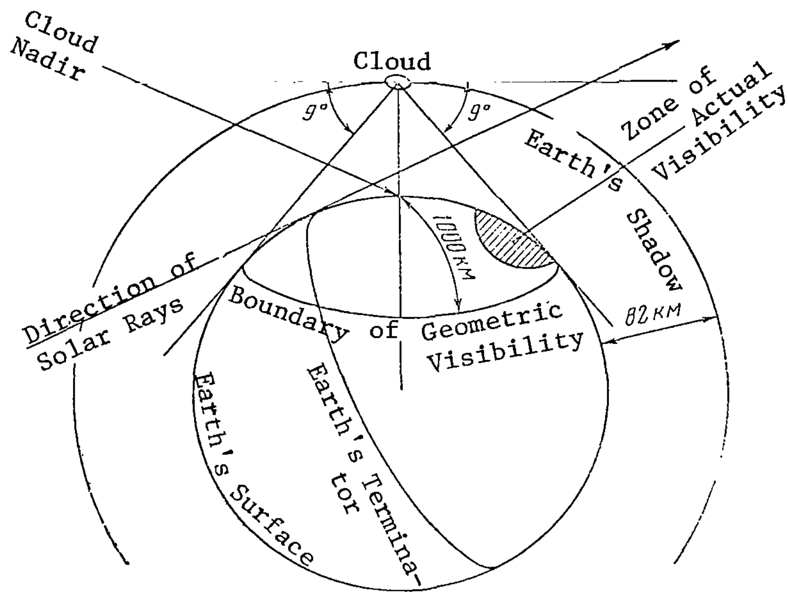

Figure 1

Conditions for Observing Noctilucent Clouds

how the optical observations are performed. It is clear that the customary methods of scientific climatology cannot be applied to this material. /145
The researcher is confronted with the complex problem: how to reconstruct the picture of the actual distribution of noctilucent clouds in time and space based on extremely incomplete and fragmatary data.

The simplest method of processing the observational material statistically will be to obtain the frequency h with which noctilucent clouds can be observed for a certain station or groups of stations, which can be expressed by the equation

$$h = t/T, \tag{1}$$

where t represents the period of time in which noctilucent clouds are actually visible, and T - the period of time in which they would be visible if they existed. Under the IGY program, we carried out the two studies described below on obtaining and investigating the characteristics of h.

We first compiled all the cases available to us in which noctilucent clouds were observed in our country from 1885 to 1956. After suitable critical evaluation and after excluding erroneous, duplicated, and questionable data, we combined them in a catalog - the final version of which contains 509 cases. This is a large study, and L. F. Gromova later processed the data obtained. The catalog data, divided according to 10-day calendar periods and latitudinal zones, present a distribution of the cases in which noctilucent clouds appeared both in time and in space. We can thus designate the obtained distribution as an apparent distribution, because it is distorted by different selective sources which are particularly related to the annual and latitudinal variations in such factors as the duration of twilight and troposphere cloudiness.

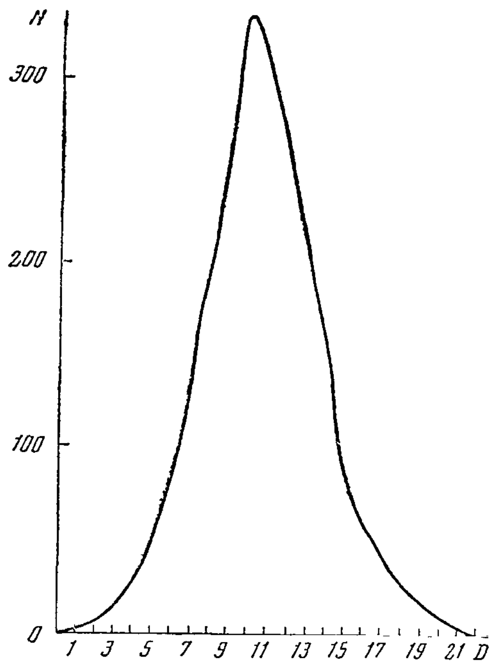

Figure 2

Dependence of Number of Cases in Which Noctilucent Clouds are Visible on Depth D of Solar Depressions

However, the duration of twilight can be readily determined by an astronomical calculation, while the effect produced by a cloudiness change for a long period of time, such as 71 years, can be fairly reliably calculated on the basis of data regarding the probability of an overcast or clear sky which are presented in climate atlases. This makes it possible to employ the catalogue data to obtain the relative values of the actual frequency h', while the time t can be set proportional to the number of published cases in which noctilucent clouds are observed. The time T represents the duration of twilight multiplied by the probability of a clear sky. However, such a calculation cannot exclude such an important factor as the difference in the amount and activity of observers at different locations and at different times.

Data which do not have the latter disadvantage can only be provided by observations performed at a network of stations spaced evenly throughout the entire country. The first attempt to organize such observations was made in the USSR during the IGY, when the program of the Hydrometeorological Service stations included the recording of cases in which noctilucent clouds were observed. This comprised a second direction to be pursued in the field of climatological research of noctilucent clouds. /146

Since the great number of observations carried out in previous years by certain experienced observers has shown that noctilucent clouds are not observed at a latitude close to 40°, the regular observations included Hydrometeorological Service (GMS) stations which participated in the IGY program and were located to the north of the 42.5° N parallel. There were 220 such stations, and they covered the country more or less uniformly. In accordance with data from the first work section, observations were performed from March 1 to October 31, in hours of the day corresponding to solar depression values D from 6 to 18°. The observations were performed as follows: the observer on duty examined the celestial vault every 15 minutes, and used a special journal to record the time, the presence or absence of noctilucent clouds, the apparent brightness of the latter based on a visual, five-point scale, and data regarding the cloudiness of the lower levels (this will be discussed below).

The performance of such a plan required numerous and extensive organizational procedures. The Astronomical Observatory of Leningrad University directed the program on noctilucent clouds. Observational data were sent from the stations to the observatory, and the processing of all the material was concentrated there. This processing comprised several consecutive stages, the most important of which were as follows: a preliminary examination of the information and correspondence with the stations with respect to any defects which were discovered; compilation of a summary on forms prepared for transmittal to the MTsD; a study of the apparent distribution for the occurrence of noctilucent clouds; determination of the actual frequency with which these phenomena appeared. In order to fulfill this work program, a special group for the purpose of studying noctilucent clouds, directed by T. D. Bessonova (Pavlova), was set up under the Laboratory of Planetary Astronomy of the Leningrad University Astronomical Observatory. In addition, in order to perform methodical work and to verify the instructions by means of practical observations, a station was set up in the town of Petrodvorets at the Biological Institute of Leningrad University. Methodical observations of the noctilucent clouds were skillfully performed here throughout the IGY.

The network of stations encountered significant difficulties in performing this new type of observations which were new to them, because the majority of them had no experience in observing noctilucent clouds, and the relative infrequency with which they appeared made it impossible to rapidly acquire the requisite experience. In 1957, the number of stations performing observations on noctilucent clouds was 109; in 1958 - 208; and in 1959 - 213.

When the observations were initiated, many different shortcomings were encountered, and even outright errors. These errors included the observers mistaking other formations for noctilucent clouds (for example, gaps between bands of cirrus) and of real noctilucent clouds remaining unidentified (for example, they were assumed to be aurora polaris). It was not until 1959 that the proper experience had been accumulated, and the observations were of the requisite quality.

The following two computational units were employed in the statistical processing of material received from a station.

1. The case of visibility, representing the observational period during which noctilucent clouds were visible from the station. It can be readily seen that the sum N of such units for a certain interval of time is proportional in the first approximation to the period of time t during which noctilucent clouds were observed from a given station.

2. We shall use n to designate the night during which noctilucent clouds were observed once or several times (regardless of how long they existed). By dividing the material with respect to dates, zones of geographical latitude, and intervals of geographic longitude, we can /147
obtain the distribution of the numbers N and n with respect to the arguments of time and space. But this distribution will only be apparent. The results of this study have already been published in several reports by T. D. Bessonova (Pavlova). We would like to point out that the total values of these sums over all three observational years were: n = 213, N = 2309.

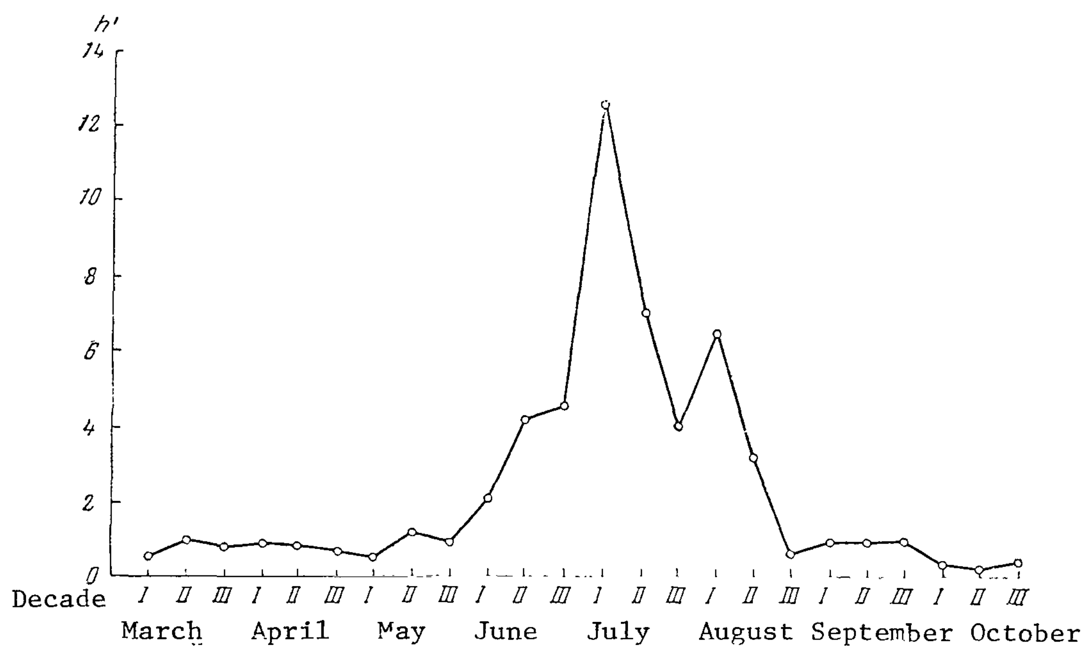

Figure 3

Annual Variation in Frequency of Noctilucent Cloud Occurrence

In order to be able to change to the actual distribution - i.e., to the distribution which was as free as possible from the effect of such factors as the weather conditions or the duration of twilight at the observational point - for each observational period corresponding to the time in which noctilucent clouds might possibly be observed, the observers had to report upon the condition of the celestial vault in the region of the glow using the following arbitrary scale: A - clear; B - individual clouds present in the upper level, intersected by clear gaps; C - clouds present in the middle or lower level with gaps; D - gaps in clouds at the middle and lower levels covered with cirrus; the glow region completely covered with clouds or fog. It was apparent that the presence of partial cloudiness in the low levels does not exclude the possibility of observing noctilucent clouds. However, the probability P that these clouds will be actually observed is less than it is for clear weather.

If we designate the number of cases (characterized by the power x) in which the glow region is covered by M_x, and the corresponding probability of observing the noctilucent clouds by P_x, then the actual visibility frequency - which was previously represented by formula (1) - can be calculated by the following formula in the second approximation:

$$h = \frac{\Sigma N}{\Sigma_A^E P_x M_x}. \qquad (2)$$

For x = A, we can set P = 1; for x = E, we will apparently have P = 0. For the remaining degrees on the scale it is difficult to determine P. However, our data justifies the assumption that for x = B, the value of P will be quite close to unity. Taking the fact into account that cases C and D are scarce, we calculated the approximate values of the actual frequency h' according to the following formula:

$$h' = 100\,000 \cdot \frac{\Sigma N_A + \Sigma N_B}{\Sigma M_A + \Sigma M_B}. \qquad (3)$$ /148

The table below and Figure 3 show the annual variation in the distribution of noctilucent clouds expressed by numbers calculated for decades, without making a separation by latitudinal zones. Only data for 1958-1959 were employed, since in 1957 observations under the IGY program were only initiated on July 1. We can see that in March and April the frequency of noctilucent cloud appearance remained at a low level. In the middle of May, a steep rise in h' began, which led to a sharp maximum in the first decade of July, followed by a sharp drop, so that in September and October, the frequency again was low.

The distribution by latitudinal zones is as follows (see also Figure 4):

Latitude of Mean Parallel in the Zone, °N..	40	45	50	55	60	65	70
h'....................................	0	87	100	414	394	204	32

In the 40° zone, which was not encompassed by our observations, noctilucent

DISTRIBUTION OF FREQUENCY OF NOCTILUCENT CLOUD
APPEARANCE BY DECADES BETWEEN 1958-1959

Month	Decade	h'	Month	Decade	h'
March	I	50	July	I	1500
	II	80		II	710
	III	59		III	442
April	I	86	August	I	604
	II	52		II	363
	III	65		III	64
May	I	54	September	I	93
	II	118		II	66
	III	91		III	125
June	I	258	October	I	36
	II	491		II	18
	III	524		III	44
			The Mean for 8 Months . . .		256

clouds were not once observed, although several researchers in previous years have persistently tried to discover them. Therefore, for this zone we can set h' = 0. A sharp increase in h' is obtained with latitude, leading to a maximum at latitudes of 55 and 60° (according to some data h' has the largest value for 55°; according to other data - for 60°), and a sharp drop for the 70° zone. The correctness of the latter fact requires verification.

The longitudinal distribution, expressed by numbers of the corresponding time zones combined by pairs,is as follows (see also Figure 5); /149

Time Zone	II-III	IV-V	VI-VII	VIII-IX	X-XI
h'............	332	342	177	198	166

A monotonic, although small, decrease in h' is obtained from west to east. This result, derived from the first attempts to make such a comparison, requires further verification and refinement.

In general, it is not possible to study the annual variation in the frequency of noctilucent cloud occurrence by means of optical observation, since the time in which these clouds are visible is limited by two short intervals of morning and evening twilight. The only thing which can be done is to compare the number of their occurrences in the morning and the evening. Employing the numbers N directly and designating their overall sum for the morning periods during the year by N_y, and for the evening periods by N_b, we can readily calculate the relationship

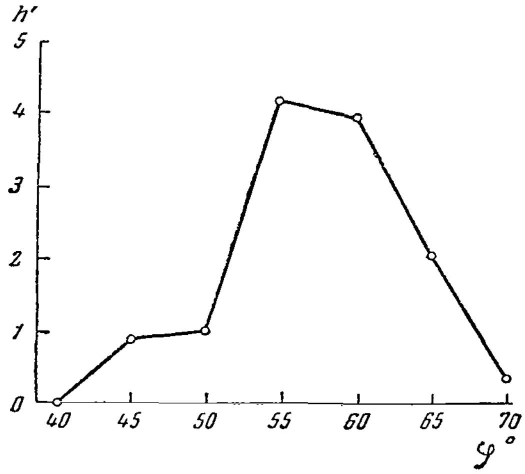

Figure 4

Latitudinal Variation in Frequency of Noctilucent Cloud Occurrence

$$Q = N_y/N_B \tag{4}$$

We obtain

Year	Q	Year	Q
1957.	1.53	1959.	1.54
1958.	1.74	Throughout the Entire Period. . . .	1.63

The predominance of the morning cases of visibility will be apparently retained when the material is further divided by months and latitudinal zones.

In conclusion, it is interesting to compare the results derived by T. D. Bessonova (Pavlova) from regular observations during 1957-1959 with those obtained from non-systematic material from 1885-1956 (L. F. Gromova). The following is obtained based on the main characteristics (Roman numerals designate decades in a given month):

	1885-1956	1957-1959
Earliest Occurrence.	April, II	March, I
Latest Occurrence.	Oct., I	Oct., III
Maximum Number of Occurrences.	July, I	July, I
Northernmost Observational Point	65.4° N	71.5° N
Southernmost Observational Point	46.4° N	45.5° N
Latitudinal Zone With Maximum Number of Occurrences	55° N	55° N

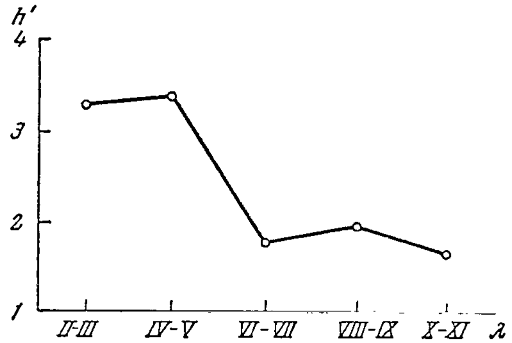

Figure 5

Change in Frequency of Noctilucent Cloud Occurrence With Geographic Longitude

As we can see, in spite of the very diverse nature of the material and the diverse methods by which it was processed, the results coincide fairly closely. New data can only extend somewhat the time and latitudinal intervals during which noctilucent clouds are observed.

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